Association of Natural Gas Hydrate Distribution in the Northern Gulf of Mexico with Bottom Simulating Reflection Profiles.

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Abstract

Gas hydrates are crystalline structures containing concentrated amounts of methane within an ice-like form. Understanding gas hydrate distribution in nature is important for determining their energy production potential and role in the carbon cycle. In this project, I look at four major protraction areas in the northern Gulf of Mexico: Alaminos Canyon, Keathley Canyon, East Breaks, and Garden Banks. I compare known bottom simulating reflectors (BSRs) identified on exploration seismic, which are thought to indicate a gas hydrate reservoir, to recently discovered natural gas hydrate occurrences on well logs from the Gulf of Mexico. Through mapping both the BSR and well log data sets, I find in only one major protraction area, Alaminos Canyon, is there a clear link between BSR occurrence and natural gas hydrate identified on well logs. In three other major protraction areas I observe no such connection between identified BSRs and gas hydrate identified from well logs. Overall, it appears that bottom simulating reflectors may not be a clear indicator of natural gas hydrate, but are useful in association with geophysical well logs.

Introduction

Natural gas hydrates are a part of the clathrate group, composed of water molecules forming a crystal lattice of cages that contain a molecule of natural gas, such as methane (Thakur and Rapjut, 2011). They are crystalline solids that resemble ice, but due to the methane molecule contained within the crystalline cage are combustible. The total amount of methane present within a methane hydrate is dependent on the structure or clathrate geometry. For example, one cubic meter of pure methane hydrate can hold up to 164 cubic meters of natural gas (Kvenvolden, 1993). This storage capacity attracts interest in using gas hydrates a potential energy resource.

Formation of gas hydrate is dependent on temperature, pressure, salinity, and presence of natural gas and water. The gas hydrate stability zone (GHSZ) is the region from the seafloor and throughout the shallow sediment that fall within the specific pressures and temperatures that gas hydrate can exist in a stable form. Changes in the depth, geothermal gradient and gas composition conditions will affect the thickness of the GHSZ (Thakur and Rapjut, 2011). Gas hydrate formation will only occur at low temperatures and high pressures which typically restrict gas hydrate occurrence to deep oceanic and arctic regions (Kvenvolden, 1993). In the Gulf of Mexico, gas hydrates are found within the sediment of the slope and rise of the continental margin (Kvenvolden, 1993). Specifically, gas hydrate occurrence has been reported predominantly in the northern slope of the Gulf of Mexico (Boswell et al., 2012).

Gas hydrate occurrence can be inferred from seismic reflection profiles of a bottom simulating reflector (BSR) (Shipley et al., 1979). BSRs coincide with the predicted depth of the base of the GHSZ. Bottom simulating reflectors mimic the bathymetry of seafloor, but cut across bedding showing no relationship to the stratigraphy (Shedd et al., 2012). They mark the boundary between the lower sonic velocity free gas zone below and higher velocity gas hydrate sediment above. The two most common types of BSRs are either attributed to gas hydrate occurrence or related to the diagenesis of siliceous sediments (Berndt et al., 2004). All of the BSRs identified within the northern Gulf of Mexico have been attributed to natural gas hydrate occurrence (Shedd et al., 2012) (Figure 1). Most of these cases are not continuous bottom simulating reflectors, but rather, discontinuous events. Continuous BSRs are the classic BSR, which produce a clear, uninterrupted reflector that mimic the seafloor bathymetry. Discontinuous BSRs are widely spaced disparate events that mimic the seafloor bathymetry (Shedd et al., 2012).

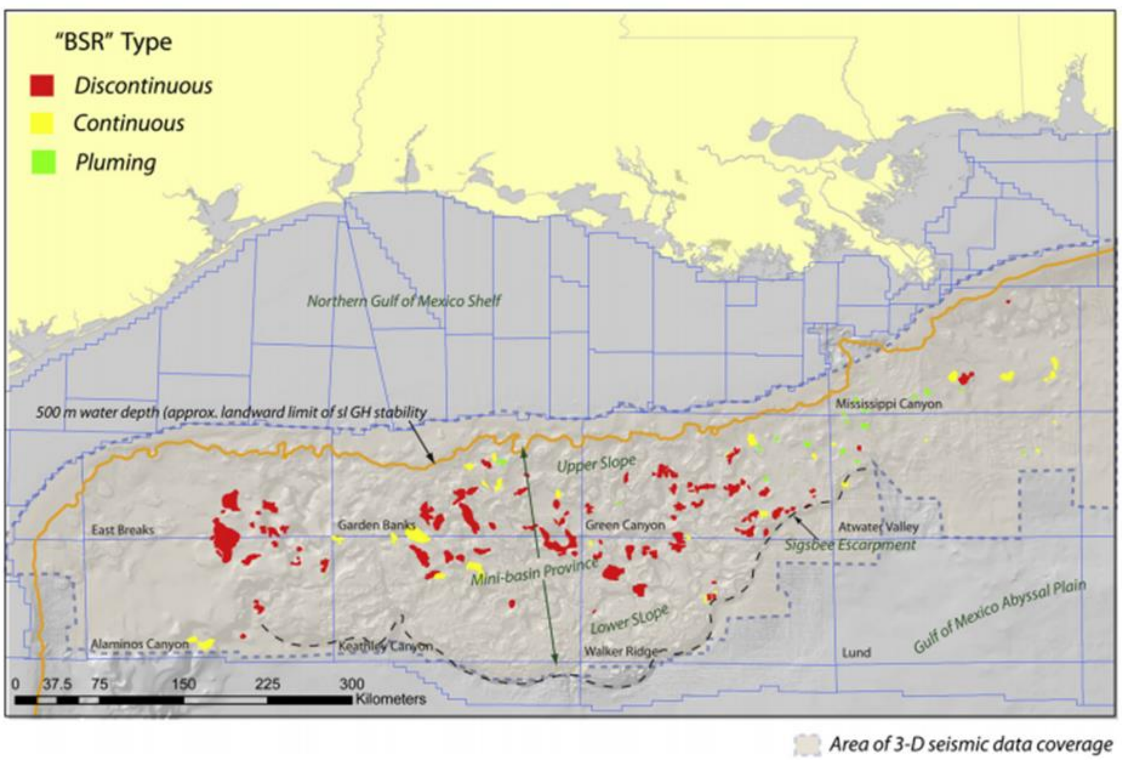

Figure 1. Map of the seafloor morphology of the northern Gulf of Mexico, and locations of BSRs shown in Shedd et al. (2012).

A number of drilling cruises have been conducted to study the *in situ* properties of gas hydrate and distribution in the Gulf of Mexico. In 2008, the Gulf of Mexico Joint Industry Project led by Chevron and the Department of Energy operated a drilling and logging campaign to understand gas hydrate occurrence (Hutchinson et al., 2008). These expeditions have provided insight into hydrate distributions, chemistry, host lithology, distribution within sediment, sediment depth, and water depth (Boswell and Collett, 2011). Observations from drilling cruises have also been used to develop models of gas hydrate occurrence. Approximately 450,000 square kilometers were assessed in the Gulf of Mexico by Minerals Management Service to help develop a model to help identify potential quantities of hydrate in the outer shelf (Frye, 2008). For the Gulf of Mexico, there is an estimated 100 GtC of gas-in-place attributed to gas hydrate reservoirs in sand (Boswell and Collett, 2011).

Methods

In a project at Ohio State University, a team is identifying natural gas hydrate on petroleum industry well logs in the northern Gulf of Mexico. Wells are categorized by the name of the surveyed oil and gas leasing section (protraction area) and the specific block number (3x3 mile squares). The team has completed well log analysis for natural gas hydrate in protraction areas Alaminos Canyon (AC), East Breaks (EB), Keathley Canyon (KC), and Garden Banks (GB) (Figure 2). In this study, I compare our results to the continuous and discontinuous BSR occurrences in the northern Gulf of Mexico from Shedd et al. (2012) to see if BSRs can be used to confidently identify natural gas hydrate reservoirs.

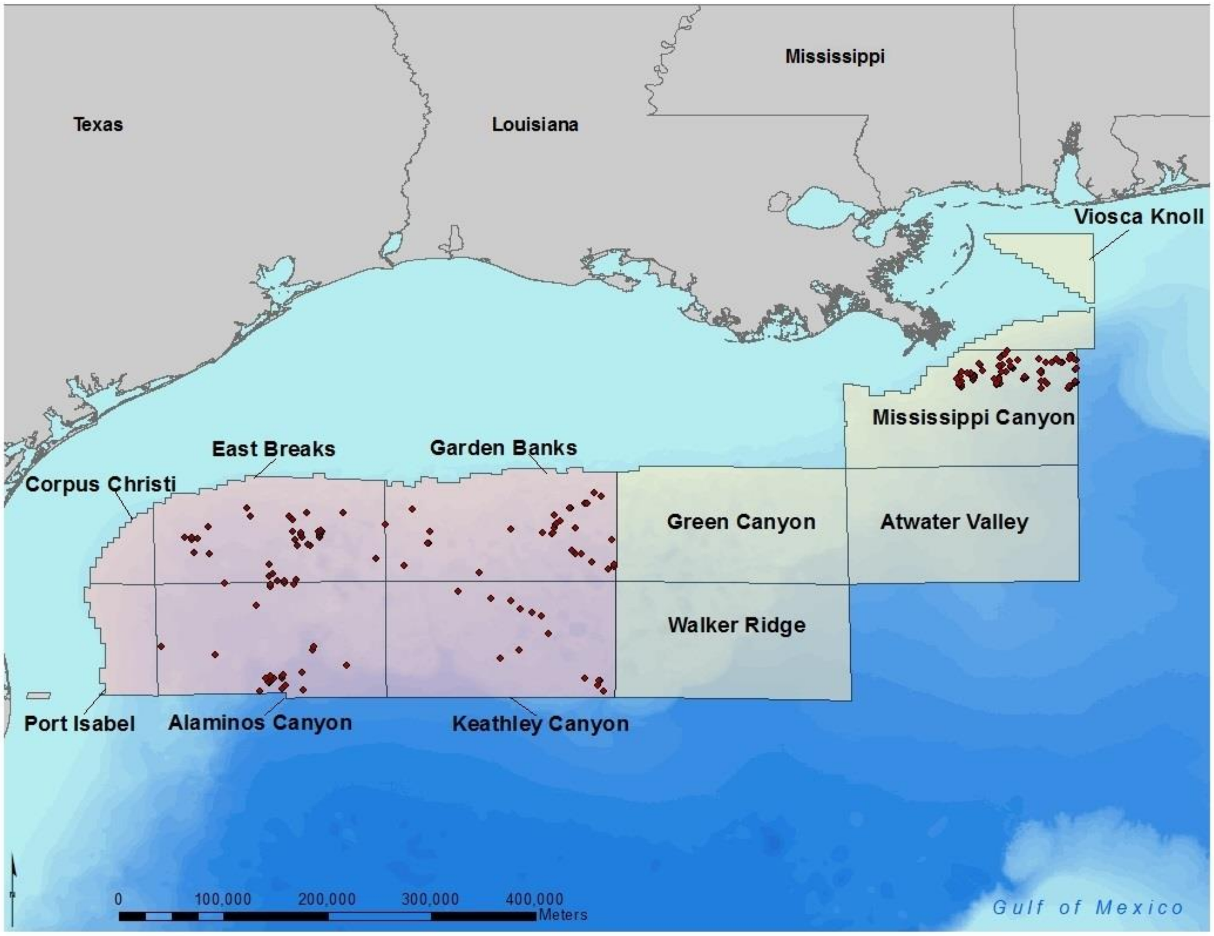

Figure 2. Map of total wells assessed in the northern Gulf of Mexico protraction areas. Completed protraction areas in pink.

To identify natural gas hydrates, the team analyzed petroleum industry well logs from 132 wells located in the northern Gulf of Mexico. Due to the type of sediment and depths of these wells, only gamma ray and electrical resistivity logs are available (Majumdar et al., 2014). Gamma ray logs are used to identify the lithology of the subsurface units. Gamma ray tools measure the amount of natural radiation within a formation, which can give an indication of the lithology. Clays have high concentrations in radioactive material and typically high gamma ray responses are inferred as being clay. Resistivity is a measurement of the relative ease of electrical conductivity within a formation. The matrix or grains within a rock are typically electrical insulators, so the resistivity is usually a measurement of the fluid within the pores. Conductive fluids such as brine or seawater will give a low resistivity response. In contrast, gas hydrate in the pore space significantly increases the electrical resistivity.

In a gas hydrate bearing sediment, there is a high measured electrical resistivity when compared to a water-saturated zone. For each well, a background resistivity was selected and deviations over 0.5 ohm*m were considered to be natural gas hydrate. Once all of the wells were analyzed for the Alaminos Canyon, East Breaks, Garden Banks, and Keathley Canyon protraction areas, all of the data were combined with bathymetry and shapefiles provided by the Bureau of Safety and Environmental Enforcement (BSEE) to create maps of the results.

Results and Discussion

Using ArcGIS, I mapped all of the wells with available data within the GHSZ and the wells showing evidence of hydrate. Specifically, these maps show percentage of data we have available for each of the wells, total feet of data within the gas hydrate stability zone and total feet of evidence of gas hydrate (total gas hydrate show) (Figures 3–5). Our assessed wells maps were compared to the bottom simulating reflector map published by BOEM to determine if a relationship between our gas hydrate bearing wells and the locations of BSRs exist (Figures 6–7).

Three of the four protraction areas, Alaminos Canyon, Keathley Canyon, and East Breaks displayed evidence of hydrate (Table 1). Garden Banks did not show evidence of hydrate, but had 33 wells within the hydrate stability zone. Alaminos Canyon contained the second highest number of wells

(39 total). In addition, six wells in Alaminos Canyon displayed evidence of hydrate. Alaminos Canyon also has the highest total feet of gas hydrate show in a well (AC 810, 690 feet).

Protraction Area	Number of Wells	Wells Intersecting BSRs	Total Hydrate Wells	Total Hydrate Wells Intersecting a BSR
AC	39	19 (59.4%)	6	5 (83.3%)
EB	47	3 (6.4%)	8	1 (12.5%)
KC	13	5 (38.5%)	2	0 (0%)
GB	33	2 (9.1%)	0	0 (0%)

Table 1. Total number of wells, total wells intersecting BSRs, total hydrate wells, and total hydrate wells intersecting BSRs in Alaminos Canyon, East Breaks, Keathley Canyon and Garden Banks protraction areas

Alaminos Canyon had the deepest wells of all four protraction areas, occurring under water columns of approximately 4000 to 9000 feet. Initially, Block AC 857 was thought to contain 9 wells showing gas hydrate intervals of 30 to 426 total feet (Figure 3). After further analysis it was confirmed that the high resistivity shows may be attributed to gas condensate rather than gas hydrate. In Block AC 856, a well showed a total gas hydrate interval of 146 feet. Block AC 818 contained a well showing a high gas hydrate show of 130 feet (Boswell et al., 2009). In addition, a well in Block AC 557 displayed a total feet of gas hydrate show of approximately 97 feet.

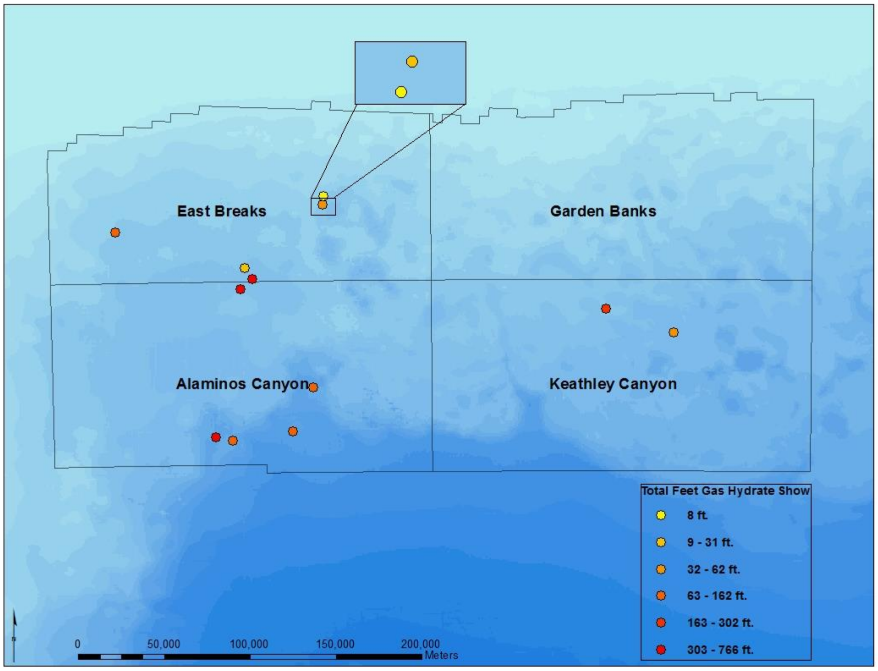

Figure 3. Map of total feet of gas hydrate show for wells analyzed in four protraction areas in the northern Gulf of Mexico.

Five wells that contain gas hydrate in Alaminos Canyon intersect BSR profiles. The northern wells intersect with a discontinuous BSR, and the southern wells intersect a continuous BSR. Of the five wells, four wells within blocks AC 810, AC 856, AC 818, and AC 557 display evidence of hydrate. The well in block AC 21 did not intersect the discontinuous bottom seismic reflector profile.

Eight wells within East Breaks displayed evidence of gas hydrate. East Breaks also has the second highest amount of total feet of data available within the GHSZ (Figures 4–5). Block EB 990 has a total of 522 feet gas hydrate show. Only one of the eight hydrate bearing wells intersects a bottom seismic reflector profile. In addition, the BSR is classified as being discontinuous. Two further wells intersect the profiles of discontinuous BSRs, but did not show evidence of hydrate.

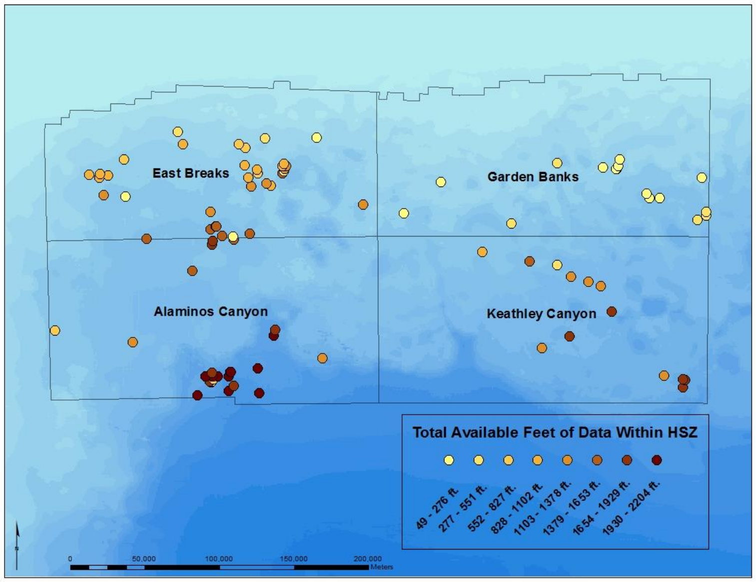

Figure 4. Map of the total feet of data available within the hydrate stability zone for each well.

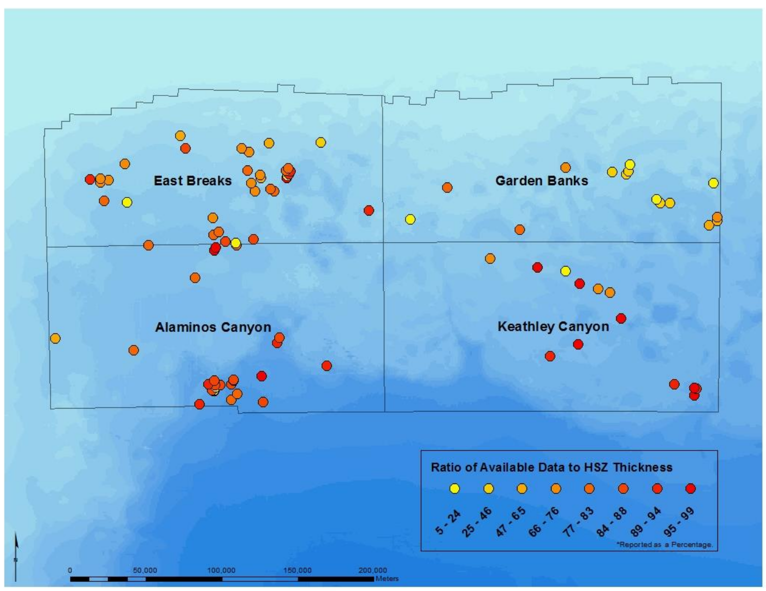

Figure 5. Map of the ratio of available data to hydrate stability zone thickness for wells in four Gulf of Mexico protraction areas.

In the Keathley Canyon protraction area, two wells displayed evidence of gas hydrate. Block KC 291 contains a well showing evidence of 62 total feet of gas hydrate. This well does not intersect a bottom seismic reflection profile (Figure 6). Furthermore, a well within Block KC 151 displays 225 feet of total gas hydrate show. The well in Block KC 151 does not intersect a BSR profile, but is in close proximity to a discontinuous BSR. In total, thirteen wells were analyzed, but only five wells intersected continuous or discontinuous BSR profiles, however, no hydrate bearing wells in Keathley Canyon intersected a BSR profile (Figure 7).

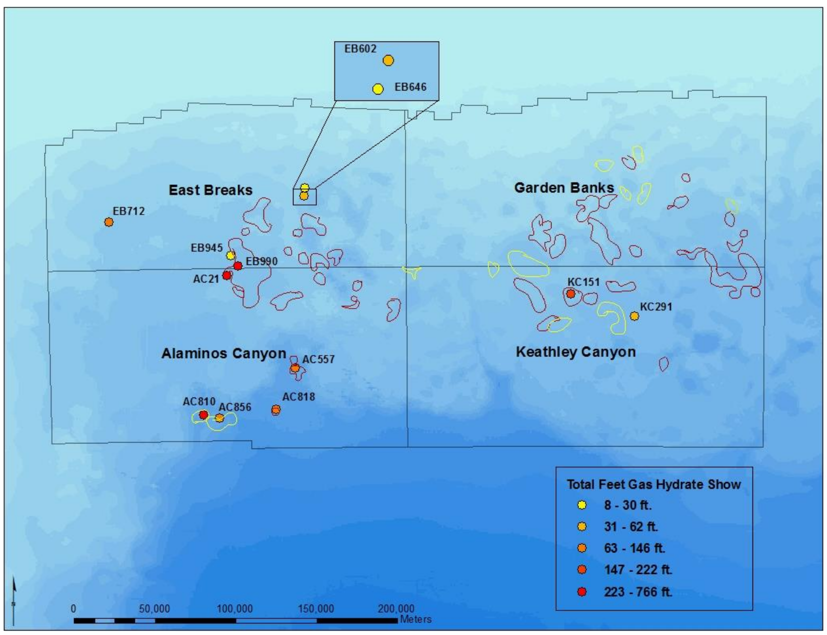

Figure 6. Map of total feet gas hydrate show and locations of bottom seismic reflectors within four protraction areas in the Gulf of Mexico. Discontinuous BSRs are outlined in red, and continuous BSRs are in yellow.

None of the wells within Garden Banks displayed evidence of hydrate, but this may be due to the fact that only two wells intersected the locations of BSRs (Figure 7). Moreover, Garden Banks had the lowest total feet of available data within the GHSZ, which may indicate insufficient data as the main cause.

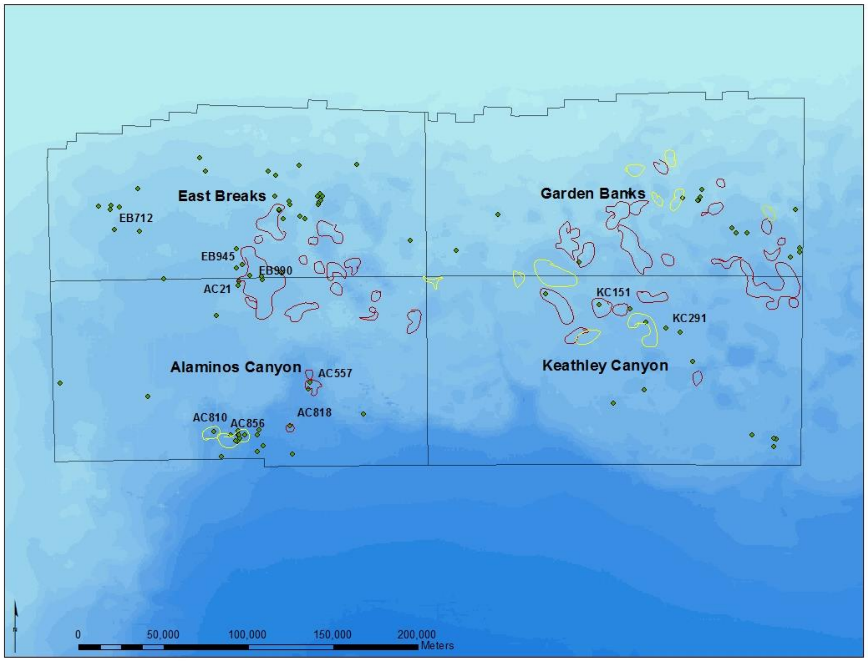

Figure 7. Map of the locations of total assessed wells and bottom seismic reflectors. Discontinuous BSRs are outlined in red, and continuous BSRs are in yellow.

After analysis of the wells within the four protraction areas it was evident that there was no significance between the locations of bottom seismic reflectors and gas hydrate occurrences in the East Breaks, Garden Banks, and Keathley Canyon protraction areas. It can be inferred that locations of bottom seismic reflectors are an indicator of the presence of gas hydrate, but gas hydrate may be present in locations where a BSR is not noted.

BSRs cannot be used to predict the presence of gas hydrate alone, but are best used in conjunction with well logging data after identifying intervals showing spikes in resistivity. BSRs can help reinforce initial interpretations from high electrical resistivity readings, and help to locate the BGHS. Due to the characteristic that low concentrations of free gas can alter velocity readings significantly, it is difficult to obtain a reasonable expression of the amount of gas hydrate present. Also, the BSR profile and base of gas hydrate stability are not interchangeable and do not always coincide. Despite this, the nature of BSR profiles in the Gulf of Mexico appears to have a significant relationship to wells showing evidence of gas hydrate in Alaminos Canyon. In wells that intersect a BSR profile, and do not show evidence of hydrate, there may be insufficient logging data.

Conclusions

Initially, due to the nature of bottom simulating reflectors, it was expected that there would be a correlation of hydrate bearing wells and locations of bottom simulating reflection profiles in the four protraction areas. After further analysis, it became apparent there was some overlap of BSRs and wells showing evidence of natural gas hydrate in Alaminos Canyon, but the majority of the wells in the remaining three protraction areas did not display a significant relationship. Consequently, it can be inferred that the most accurate method for identifying gas hydrate occurrence would be correlating electrical resistivity readings with seismic data rather than the use of BSR profiles alone

Future Work

Further analysis of bottom simulating reflectors and gas hydrate occurrence is required to determine the significance of BSRs in quantifying gas hydrates and identifying gas hydrate occurrence. Our method of using petroleum industry well logs and seismic data to identify natural gas hydrate occurrence is applicable to gas hydrate occurrence in other oceanic settings where well data or seismic data are available. Additional borehole data, and seismic of the majority of wells in the Gulf of Mexico would be ideal for strengthening methods of gas hydrate identification.

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